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Simulating the specific absorption rates in different human tissues at 4G frequencies for mobile phones

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ABSTRACT

Employing electromagnetic waves in mobile communication networks has increased the level of human exposure to electromagnetic fields that may result in concerns about health hazards associated involves the soaking up of cellular phone electromagnetic energy. The human body is penetrated by the electromagnetic fields that emit from a cell phone. The specific absorption rate (SAR) that is generated in the human head and body layers usually expresses the thermal effect on human tissue. The main objective of this paper is to investigate the thermal effects of the electromagnetic field induced inside the human head and body through the construction of a simplified model for both. The RF-source and human body models are built by using the ANSYS high-frequency structural simulator (HFSS). A planar inverted-F antenna (PIFA) will use to assign SAR values to different body tissues for the fourth generation (4G) of mobile phone communication at an operational frequency of 2.6 GHz and power radiated of 125 mW. The model is simulated and analyzed to evaluate the SAR induced at different human tissues depending on the source-to-antenna distance and its generated values must not exceed the safe limits for harmful thermal effects.

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1. INTRODUCTION

Electromagnetic fields interact with the human body, causing health concerns in recent years. As wireless networks and antennas have been used more and more recently, our surrounding environment has become polluted with electromagnetic radiation. Therefore, the study of electromagnetic fields (EMFs) and their effects on human tissue is of accomplished importance.

An effective parameter for determining how much electromagnetic power is absorbed by human tissues is the specific absorption rate (SAR) [1], [2]. A high power absorbed in the tissues after exposure to radiation will cause tissue heating. Temperature rise in human tissues is another safety standard to determine the extent of heating in biological tissues [3]. The SAR value for mobile phones must not exceed the exposure guidelines, defined as 2 watts per kilogram (W/kg) [4].

The SAR value may be affected by a variety of antenna parameters, including the power of the antenna, its position relative to the human body, and its radiation patterns [5]. SAR values are also affected by the dielectric properties of human tissues such as conductivity and permittivity, which are in turn affected by electromagnetic radiation source operational frequencies [6], [7]. Cell phone usage is studied by some researchers using a specific device (thermal imaging camera) in order to measure the changes in body temperature, from which the SAR value is calculated [8]. As opposed to this, most studies first calculated the SAR result, from which the temperature rise was derived [9]–[15]. In this study, we used the ANSYS high-frequency structural simulator (HFSS) software to model mobile phone antenna and to extract SAR distributions in the human head and body.

2. METHOD

We create a 3D model of the head. SAR is measured in the head and body of a human. Planar inverted-F antennas (PIFAs) are used in modern mobile phones. PIFA antennas have the benefit of being compact in size and having small back lobes, making them suitable for use in mobile phone antennas.

2.1. Simulation model

ANSYS HFSS software was selected for its accuracy in three-dimensional simulations (3D). Using phantom heads and human body models, SAR models are solved and analyzed. Human head and body models are spaced at 0 cm and 2 cm from the antenna, which operates at 2.6 GHz frequency.

2.1.1. Head modeling

For the purpose of simulating realistic SAR measurements, an Institute of Electrical and Electronics Engineers (IEEE) phantom model is created (ANSYS offers a millimeter-scale head model for adult females) [16], [17]. An additional model of the head consisting of four layers (skin, fat, skull, and brain) is used for this analysis. The thickness of these layers is (0.14 cm, 0.1 cm, 0.66 cm, and 8.1 cm) respectively [18]–[20]. Since mobile phones are typically placed with the face in such a manner that they appear flat with the head, layers of the head are considered flat layers. Biological tissues in the human head can be thought of as lossy dielectrics with frequency-dependent variations in their conductivity and relative permittivity. Table 1 [21], [22] outlines the characteristics of the different layers of the head.

Table 1. Human head tissue dielectric properties at 2.6 GHz

Tissue name	Conductivity (S/m)	Relative permittivity	Mass density (kg/m^3)
Skin	1.5357	37.845	1100
Fat	0.11119	5.2646	920
Skull	0.85862	18.379	1850
Brain	1.2919	35.991	1050

2.1.2. Body modeling

Using a hand model, an IEEE model of the specific anthropomorphic mannequin (SAM) phantom is created to simulate the measurement of SAR (in millimeter scale, ANSYS offers the adult-female hand model). Also, a human body tissue model is simulated as four layers (skin, fat, muscle, and bone). A box with a radiation boundary surrounds the simulation model. According to Table 2 [23]–[25], the permittivity, conductivity, mass density, and thickness of each tissue layer vary.

Table 2. Human body tissue dielectric properties at 2.6 GHz

Tissue name	Conductivity (S/m)	Relative permittivity	Mass density (kg/m^3)	Thickness (cm)
Skin	1.5357	37.845	1,100	0.2
Fat	0.11119	5.2646	920	0.5
Muscle	1.8429	52.546	1,006	2
Bone	0.85862	18.379	1,850	1.3

2.1.3. Antenna modeling

In this model, the antenna has a width of 7.14 cm and a height of 4 cm. With the help of the HFSS antenna designer kit, PIFA is designed to operate at a frequency of 2.6 GHz and emits a power of 0.125 watts as shown in Figure 1.

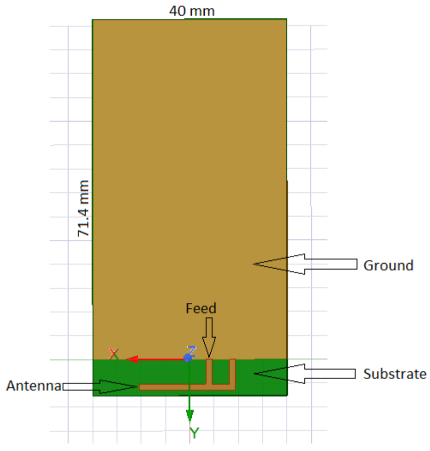


Figure 1. Planar inverted F antenna

3. RESULTS AND DISCUSSION

The reflection coefficient (S11 parameter) indicates the extent to which electromagnetic waves are reflected by transmission lines because of their impedance. Figure 2(a) shows the reflection coefficient (return loss) value as -11.5948 dB of the PIFA antenna at 2.6 GHz. Figure 2(b) shows its gain.

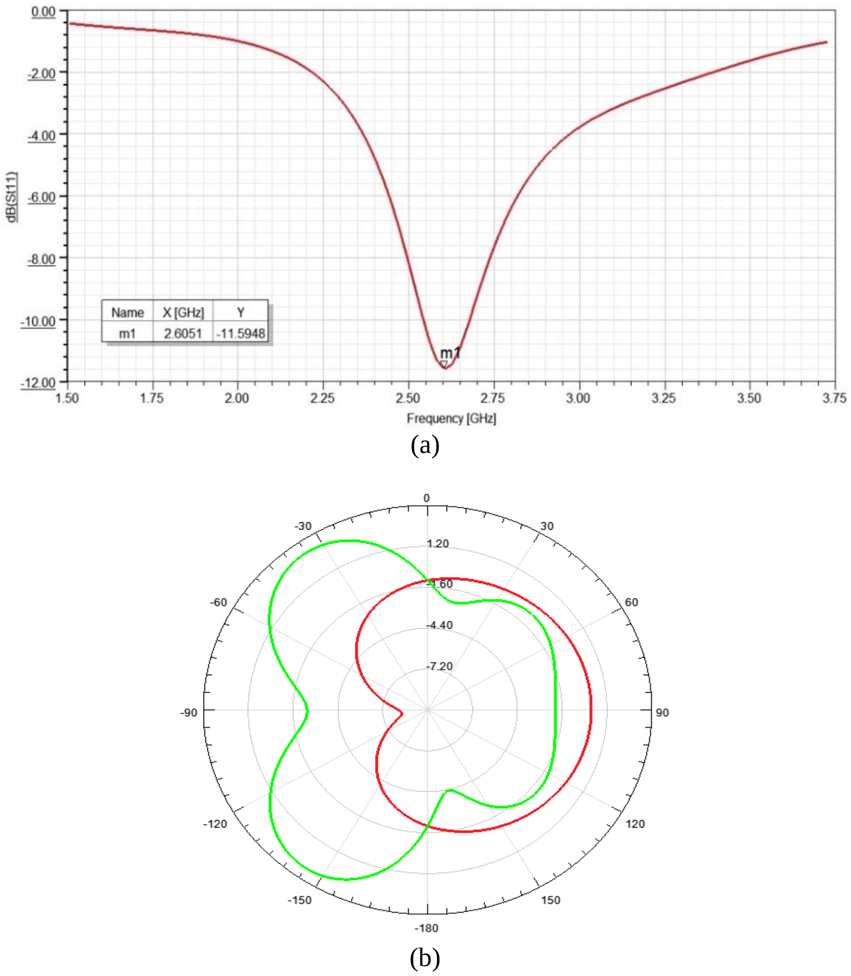


Figure 2. The simulated S11 parameter (return loss) and the gain of PIFA at 2.6 GHz (a) reflection coefficient of the antenna (return loss) and (b) the gain for the antenna

3.1. IEEE phantom model

IEEE phantom model (head model for adult female): the antenna will be placed two distances from the head to measure SAR once when the distance between the head and the antenna is 0 cm and the other distance is 2 cm as shown in Figures 3 and 4. In Figures 3 and 4, we present a simulation of the SAR (W/kg) for a volume of 10 grams of tissue at 2.6 GHz over two distances. The SAR value is 15.45 W/kg when there is no space between the head and antenna, exceeding the recommended limit of 2 W/kg. But if the distance is 2 cm, the SAR values never exceed the safety guidelines where its value is 0.233 W/Kg.

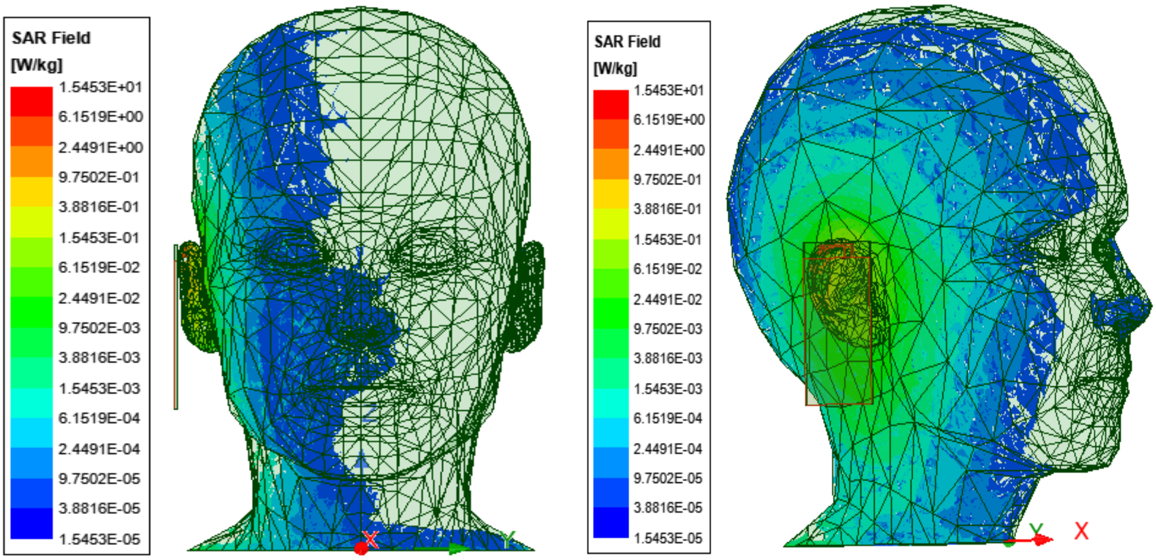


Figure 3. SAR 10 g for the human head at a distance of 0 cm

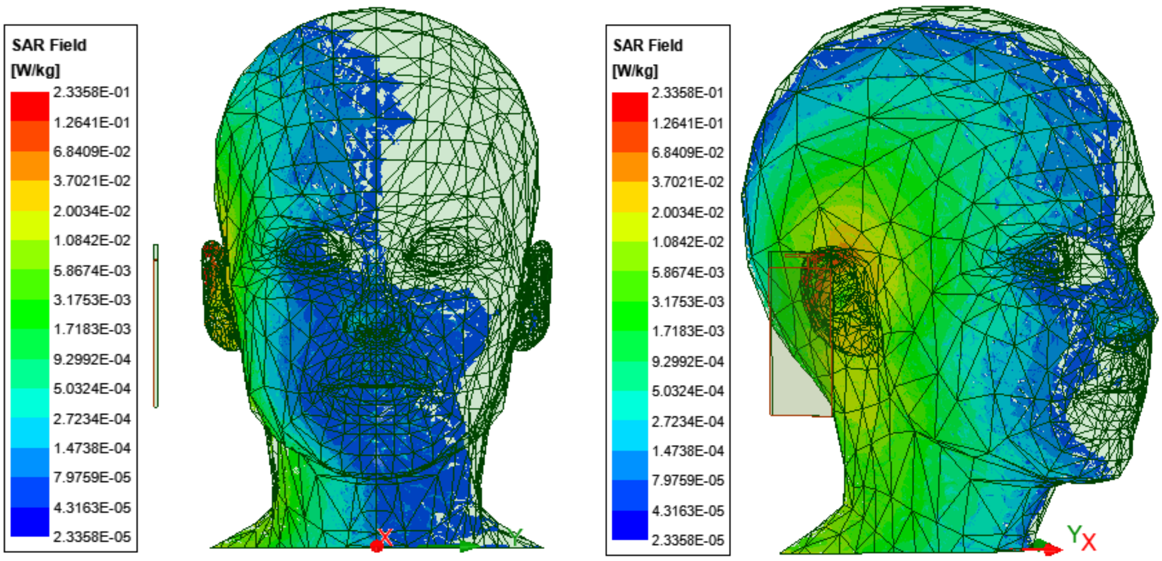


Figure 4. SAR 10 g for the human head at a distance of 2 cm

3.2. Human head model

A human head model consisting of four layers. The antenna will be placed at two distances from the head layers to measure SAR once when the distance between the head layers and the antenna is 0 cm and the other distance is 2 cm. Figure 5(a) present the maximum SAR value in the skin, Figure 5(b) the maximum SAR value in fat, Figure 5(c) the maximum SAR value in the skull, and Figure 5(d) the maximum SAR value in the brain when the distance is 0 cm. Whereas Figure 6(a) present the maximum SAR value in the skin,

Figure 6(b) the maximum SAR value in fat, Figure 6(c) the maximum SAR value in the skull, and Figure 6(d) the maximum SAR value in the brain when the distance is 2 cm.

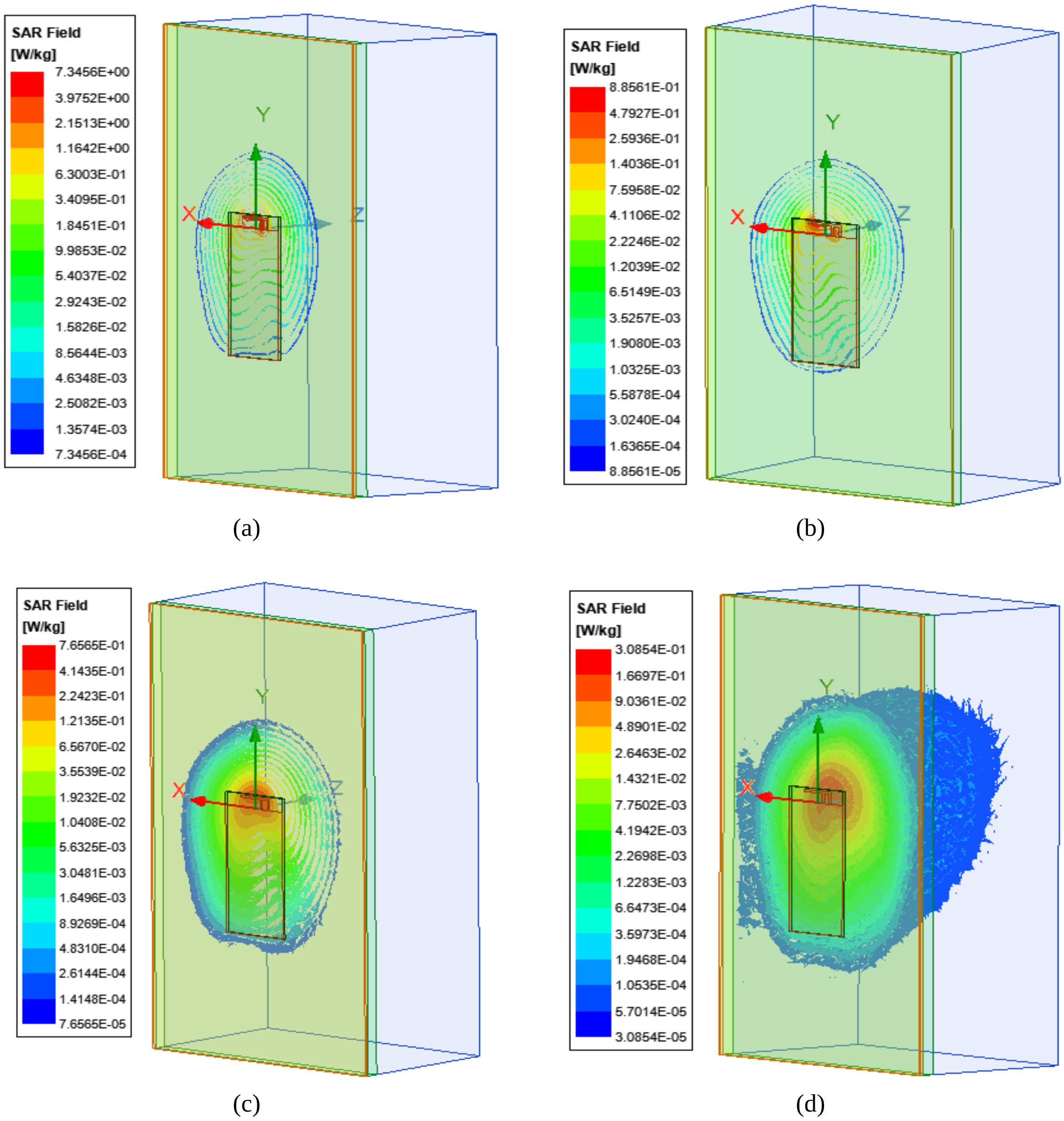
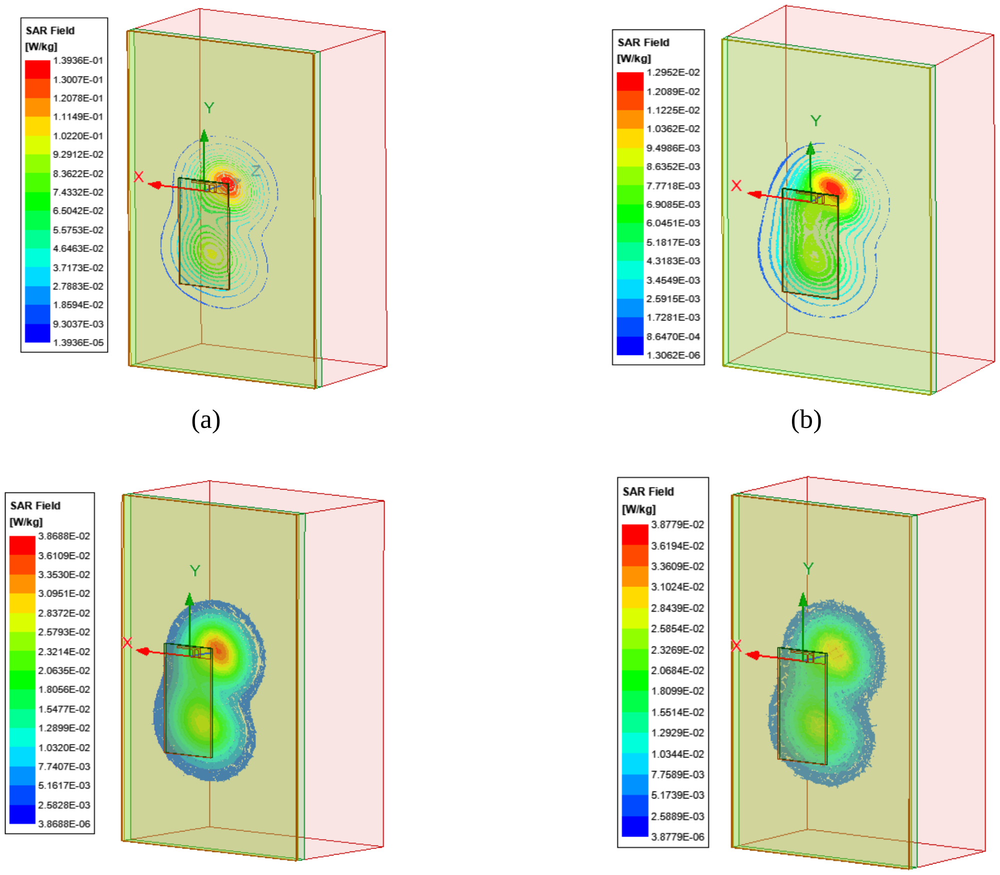


Figure 5. SAR of 10 g for human head layers at 0 cm distance (a) SAR analysis at 10 g of skin tissue (b) SAR analysis at 10 g of fat tissue (c) SAR analysis at 10 g of skull tissue, and (d) SAR analysis at 10 g of brain tissue

In Figure 5, we present a simulation of the SAR (W/kg) for a volume of 10 grams of tissue at 2.6 GHz over a 0 cm distance. When there is no distance between the layers of the head and the antenna, the SAR value in the skin tissue only exceeds the guideline (2 W/kg), where its value is 7.345 W/kg. As for the rest of the head layers, the SAR values will not exceed the safety guidelines, as their values are (0.885, 0.7656, 0.308), respectively. In Figure 6, we present a simulation of the SAR (W/kg) for a volume of 10 grams of tissue at 2.6 GHz over a 2 cm distance. In all head layers, SAR values will not exceed safety guidelines, their values are (0.1393, 0.0129, 0.0386, 0.03877) respectively.



(a) (b)

(c) (d)

Figure 6. SAR 10 g for the layers of the human head at a 2 cm distance (a) SAR analysis at 10 g of skin tissue, (b) SAR analysis at 10 g of fat tissue, (c) SAR analysis at 10 g of skull tissue, and (d) SAR analysis at 10 g of brain tissue

3.3. Human hand model

Hand model, an IEEE model of the SAM phantom. In Figure 7, we present a simulation of the SAR (W/kg) for a volume of 10 grams at 2.6 GHz. SAR values will not exceed the safety guidelines in the human hand, and their value is (1.103 w/kg) and the antenna has been rotated at an angle of 20 degrees to be in contact with the hand correctly so that the distance between them is 0 cm.

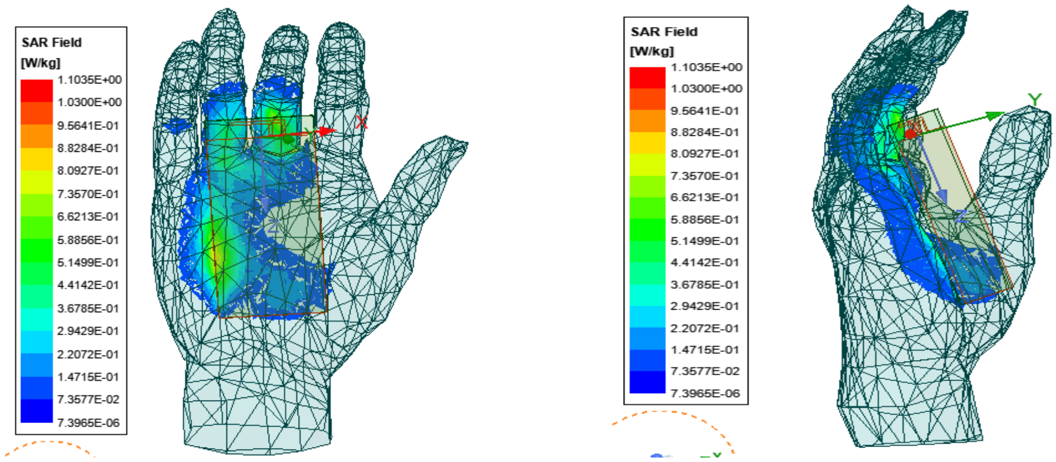


Figure 7. SAR 10 g for the human hand

3.4. Human body model

The human body model consists of four layers (skin, fat, muscle, and bone). The antenna will be placed two distances from the body layers to measure SAR once when the distance between the body layers and the antenna is 0 cm and the other distance is 2 cm. Figure 8(a) present the skin's highest SAR value, Figure 8(b) the highest fat SAR value, Figure 8(c) the muscle's highest SAR value, and Figure 8(d) the maximum SAR value in the bone when the distance is 0 cm. Whereas Figure 9(a) present the skin's highest SAR value, Figure 9(b) the highest fat SAR value, Figure 9(c) the muscle's highest SAR value, and Figure 9(d) the maximum SAR value in the bone when the distance is 2 cm.

In Figure 8, we present a simulation of the SAR (W/kg) for a volume of 10 grams of tissue at 2.6 GHz over a 0 cm distance. In the absence of a distance between the body layers and the antenna, the SAR value in the skin and adipose tissue exceeds the safety guidelines (2 W/kg) as its values are (7.833, 4.320) and W/kg respectively. As for the remaining two tissues, the SAR values will not exceed the safety guidelines, values (0.418, 0.008) respectively.

In Figure 9, we present a simulation of the SAR (W/kg) for a volume of 10 grams of tissue at 2.6 GHz over a 2 cm distance. In all body layers, SAR values will not exceed safety guidelines, their values are (0.248, 0.0189, 0.0649, 0.005) w/kg respectively. These results are roughly consistent with those obtained by [22] where they used a model of a human body in 3D using ANSYS. While we used models of layers for the human head and body.

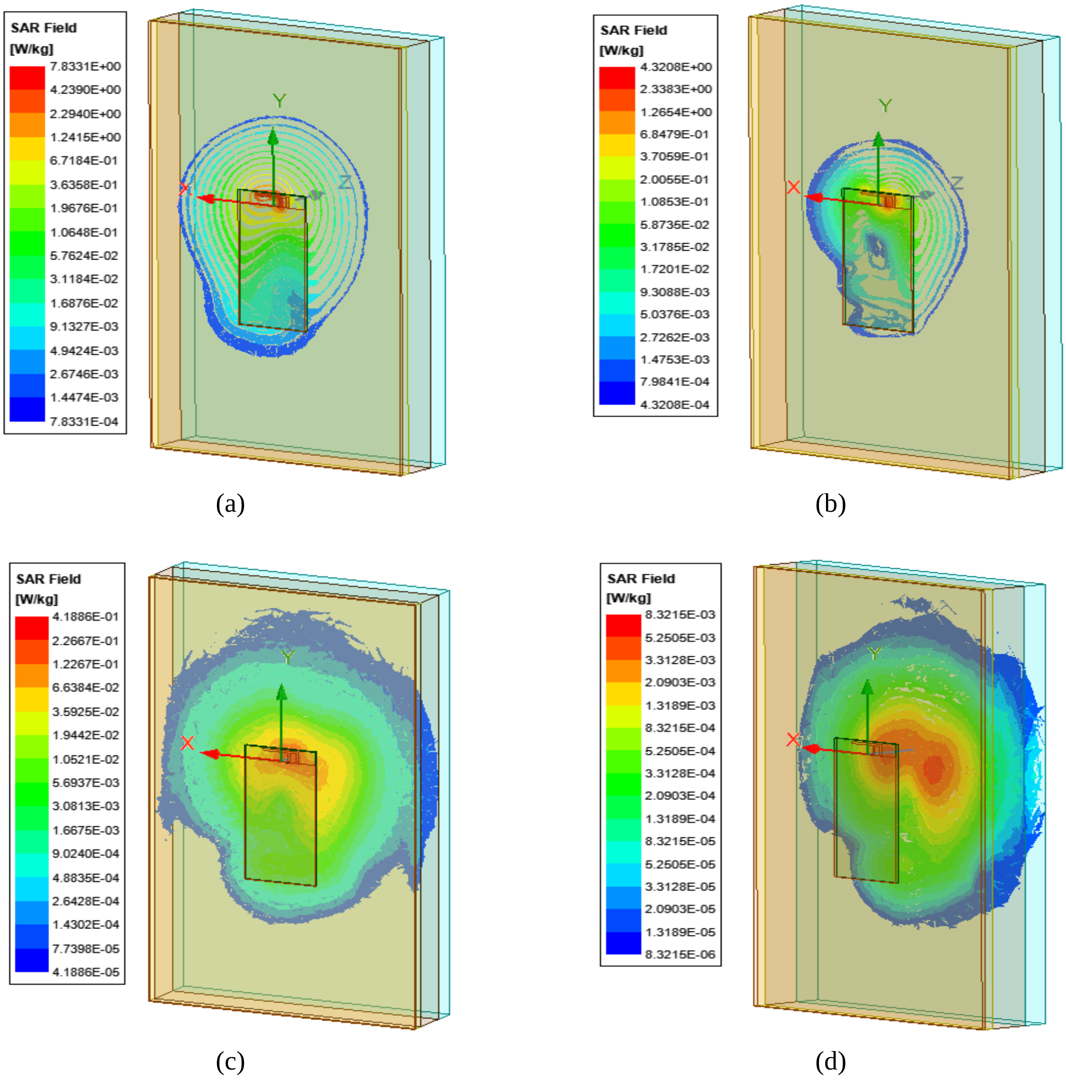


Figure 8. SAR 10 g for the human body layers at a distance of 0 cm (a) SAR analysis at 10 g of skin tissue, (b) SAR analysis at 10 g of fat tissue, (c) SAR analysis at 10 g of muscle tissue, and (d) SAR analysis at 10 g of bone tissue

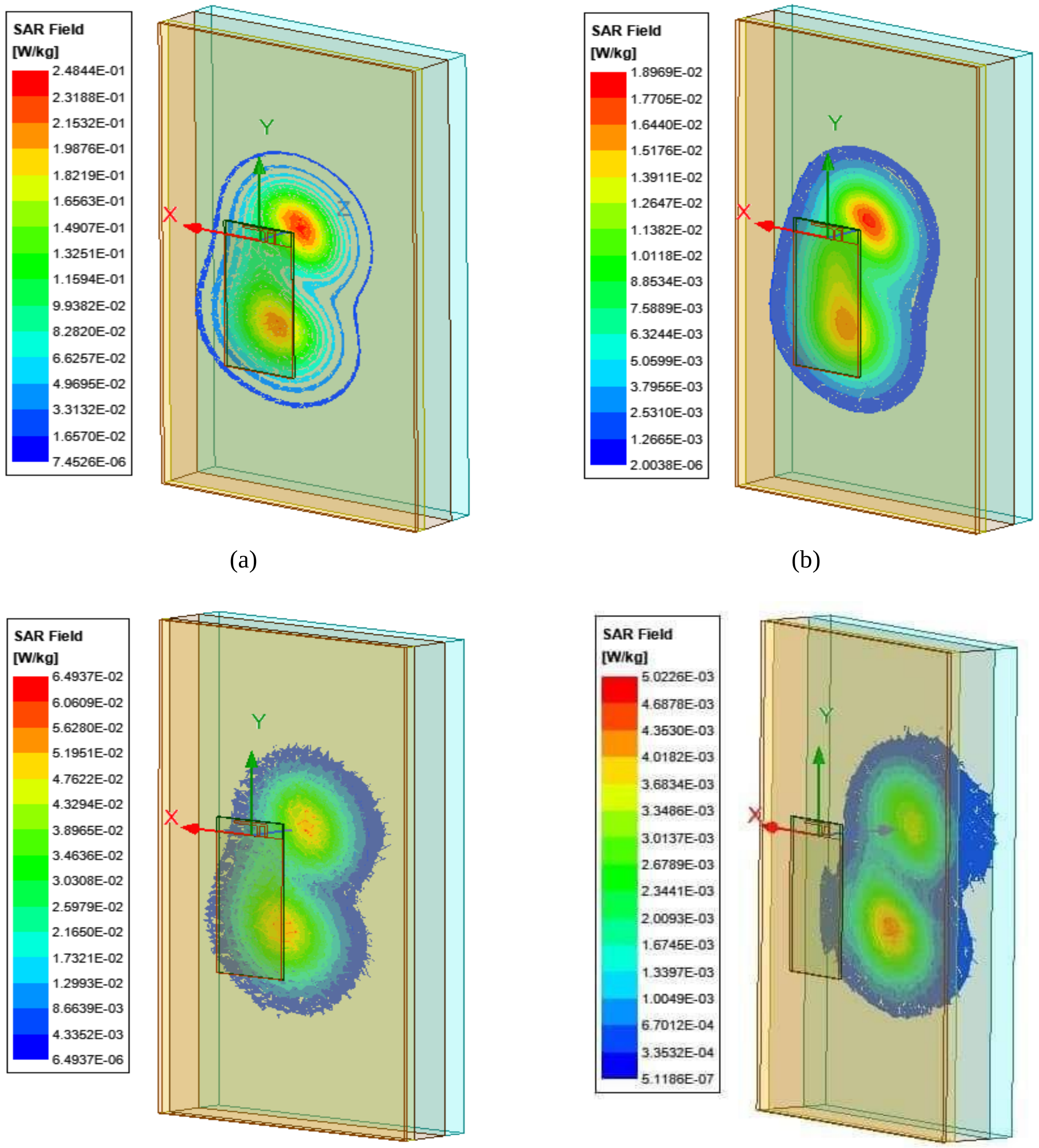


Figure 9. SAR 10 g for the human body layers at a distance of 2 cm (a) SAR analysis at 10 g of skin tissue, (b) SAR analysis at 10 g of fat tissue, (c) SAR analysis at 10 g of muscle tissue, and (d) SAR analysis at 10 g of bone tissue

4. CONCLUSION

The SAR values of this study were calculated based on phantom models of the hand and head as well as models of different human tissue layers. The simulation models are created utilizing HFSS and two distances are set between these models and the antenna (0 cm and 2 cm). It is recommended that SAR values be below 2 W/kg over 10 g of tissue to ensure compliance with the regulations of the International Commission on Non-Ionizing Radiation Protection (ICNIRP). It is observed that SAR has a value of 15.45 W/kg in the head model, (7.345, 7.833) W/kg in skin tissue, and 4.320 W/kg in fat tissue when they are 0 cm apart from the antenna. But the safety guideline is never crossed when the distance is 2 cm in all models. SAR values increase as the distance between the head or body of a human and the antenna decreases this is what the study proves through the results mentioned earlier. A higher SAR indicates radio frequency (RF) radiation might pose a health risk to the human body, especially at head layers. The limitations of this method are that the simulation is very time-consuming to perform and the use of ANSYS 3D human body model is very expensive. In future works, the signal source can be changed to study the effect of various electronic products on the human body. If we use the actual 3D model, we will no longer be limited to the head model. In the future, full-body wearable electronic devices are becoming mainstream. If the specific data of the whole human body is obtained through 3D modeling, the specific real absorption rate will be visualized. With the continuous development of communication technology, future research will also involve high-frequency bands, which will have a large gap between each generation of communication technology.

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